Ecological Impacts and Coastal Ecosystem Resiliency Following Hurricane Katrina

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The 2005 Atlantic hurricane season was the most active in recorded history, with 28 tropical and subtropical storms. Fifteen storms became hurricanes, seven strengthened into major hurricanes (Category 3, 4, or 5 on the Saffir-Simpson Hurricane Scale), and a record four reached Category 5 strength. Three of these hurricanes (Rita, Wilma and Katrina) are among the most intense Atlantic hurricanes ever recorded, and Tropical Storm Zeta, which formed at 0600 UTC on December 31 and persisted into 2006, was the second latest-forming tropical cyclone ever recorded in the Atlantic.

For many, however, the 2005 Atlantic hurricane season will be remembered for the devastation wrought by Hurricane Katrina, one of the most powerful hurricanes to hit the U.S. coastline in the last century. Centered over the Gulf of Mexico on 28 August 2005, Katrina was a Category 5 storm with estimated maximum sustained winds of 280 km hr\(^{-1}\) and hurricane- and tropical storm-force winds extending more than 170 km and 370 km, respectively, from the eye (Knabb et al. 2005). It made landfall twice on 29 August 2005, first in southeast Louisiana with sustained wind speeds of ca. 180-200 km hr\(^{-1}\) and again on the Mississippi coastline near the mouth of the Pearl River. While the storm weakened as it reached the coast and moved inland, hurricane-force winds with gusts exceeding 160 km hr\(^{-1}\) and rainfall accumulations exceeding 20 cm penetrated more than 150 km inland (Kupfer et al., in press). Katrina caused widespread, massive destruction through not only its high winds but also a storm surge that exceeded nine meters near Pass Christian and Bay St. Louis, MS, surpassing the surge associated with Hurricane Camille as the highest ever recorded along the U.S. Gulf Coast. The flooding of New Orleans, LA was catastrophic, resulting in the displacement of more than 250,000 people. Responsible for more than $80 billion in damage and more than 1800 deaths, Hurricane Katrina was the most costly natural disaster ever to strike the United States and the deadliest since the Lake Okeechobee hurricane of September 1928 (Graumann et al. 2005).

In the wake of the human tragedy and environmental damage left behind by Hurricane Katrina, the University of South Carolina’s Office for Research and Health Sciences awarded nearly $400,000 in grants to fund 18 research projects on the environmental and societal impacts of the storm as part of the university’s CRISIS (Coastal Resiliency Information Systems Initiative for the Southeast) initiative. The key to these grants was the rapid process, with awards being finalized within weeks of the hurricane. The grants thus enabled USC researchers and their collaborators at universities in the Gulf Coast, including Louisiana State University, Mississippi State University, Tulane University, the University of Southern Mississippi, the University of Memphis, and the University of New Orleans, as well as co-investigators with a range of federal and state agencies, including NOAA's National Marine Fisheries Service and National Estuarine Research Reserve System, the USDA Forest Service, the US Geological Survey and the US Army Corps of Engineers, to investigate the disaster, capture perishable data necessary to understand aspects of coastal resiliency, and examine the recovery of natural processes and ecosystems and the societal changes that occur with the relocation of residents and the rebuilding of communities. This symposium, held at the 2007 Annual Meeting of the Association of Southeastern Biologists, convened in Columbia, SC, included presentations from five of these projects that focused on the ecological effects of the hurricane and touched on the implications
for ecosystem recovery. In light of rising sea levels and predictions of increased storm intensity in the Gulf under most climate scenarios (Twilley et al. 2001), we offer the following observations in hope they will further understanding of and preparation for future hurricanes.

**Potential impacts of Hurricane Katrina on local populations of grass shrimp (Palaemonetes pugio).** Joseph M. Quattro 1, Mark A. Roberts 1 (presenter), James M. Grady 2, T. W. Greig 3 and William B. Driggers 4. 1 University of South Carolina, Columbia, SC, 2 University of New Orleans, New Orleans, LA, 3 National Ocean Service, Charleston, SC and 4 National Marine Fisheries Service, Pascagoula, MS.

The daggerblade grass shrimp (*Palaemonetes pugio*) is a widespread and common inhabitant of estuarine marshes and tidal creeks along the eastern coast of North America. Grass shrimp are an obligate food source for shrimps, crabs and most estuarine bottom-feeding fishes, making them both ecologically and commercially important. Because of their close association with aquatic vegetation, grass shrimp populations are negatively impacted by human activities that reduce habitat structure (Thorp, 1976; Heck and Crowder, 1991). Likewise, it is anticipated that natural phenomena, like major hurricanes, that destroy or alter vegetation and other forms of habitat structure, would negatively affect grass shrimp.

Our previous research shows Gulf Coast populations to be more genetically diverse than any Atlantic Coast population (unpublished data); if this measure is in any way associated with genome-wide levels of genetic diversity, Gulf Coast populations might be more likely to weather environmental changes if standing genetic diversity allows populations to adapt to changing environmental conditions. We know that grass shrimp are relatively resistant to various pollutants, likely a trait determined largely genetically, and that this trait varies substantially from one locale to another (e.g., see Schimmel et al. 1977 and Moore 1988), reflecting exposure history and projecting ability to cope with future exposure. The effect that a catastrophic hurricane, such as Hurricane Katrina, would have on both the overall abundance and the genetic diversity of grass shrimp populations is largely unknown. While it is easy to see the tragic terrestrial consequences of such events, the effects on submerged aquatic flora and fauna have remained more difficult to ascertain.

We examined mitochondrial DNA diversity in approximately 200 samples of *P. pugio* collected before and immediately after Hurricane Katrina. Our previous genetic work suggested significant population-level subdivision in this species pre-Katrina, and we were interested in the potential impacts of this event on genetic differentiation among coastal populations. An Analysis of Molecular Variance (AMOVA; Excoffier et al., 1992) that nested pre-Katrina and post-Katrina samples as “regions” (with five “impacted” coastal populations collected from Alabama through Louisiana nested within these regions) was used to detect significant genetic differentiation before versus after the storm.

Preliminary analyses suggest that a large significant, but interestingly, negative component of genetic variance can be attributed to pre- versus post-Katrina differentiation; a result that can be attributed to sampling of two rather divergent genetic lineages within one sample (Cocodrie, Louisiana). When this sample was removed, genetic differentiation across time (pre- versus post-Katrina) was small, negative but non-significant, and a larger proportion of the total genetic variance was found among samples within any one year. Our results suggest that Hurricane Katrina has had minimal impact on the population genetics of this common estuarine species.
Observing Hurricane Katrina impacts and responses in the Grand Bay, MS National Estuarine Research Reserve. Samuel P. Walker (presenter), Dwayne E. Porter, Madilyn Fletcher, and Mark S. Woodrey. University of South Carolina, Columbia, SC. Mississippi State University, Coastal Research and Extension Center, Grand Bay National Estuarine Research Reserve, Moss Point, MS.

This study assessed the impacts of Hurricane Katrina at the Grand Bay, MS, National Estuarine Research Reserve (NERR), an environmentally rich habitat that is part of the National Oceanic and Atmospheric Administration’s (NOAA) NERR System. Specifically, our goals were twofold, to: 1) assess initial impacts of Hurricane Katrina on estuarine and upland groundwater water quality and marsh vegetation condition; and 2) develop a rapid assessment plan for the Grand Bay NERR that would guide the collection of perishable data in future storm events.

We found that salt marsh habitats readjusted quickly after Hurricane Katrina, and there were no marked impacts on marsh vegetation or estuarine habitat. In this respect, the large storm surge may have been beneficial, as the marshes at Grand Bay were submerged under more than four meters of water and may have been protected from the heaviest wave- and surge-caused damage. Subsequent monitoring also determined that there was no groundwater intrusion within one month after the storm, although research to monitor possible slow intrusion in the longer term is planned. Indeed, we found that the marsh and estuary communities were markedly resilient when challenged with hurricane impacts, although longer-term change caused by increased salinity runoff from the upland forest is still a possibility. Researchers are also conducting ongoing monitoring of marsh vegetation communities, with sampling of emergent grasses and coastal woodlands for long-term effects.

The high resiliency of the salt marsh habitat contrasted markedly with developed areas and human-created structures, which experienced heavy damage. Such damage posed logistical challenges for conducting a rapid, post-disturbance assessment of ecological conditions on the reserve so one of our first actions was to help re-establish storm-damaged monitoring instrumentation and data streams crucial for tracking time-scales of recovery in this ecosystem. We also developed a rapid response plan to facilitate documentation of near-term impacts in future storm events; the intention is that the plan will serve as a template for other NERR sites. Through the development of rapid assessment plans for determining impacts to high-value estuarine communities, researchers will be able to better understand and protect the integrity of the nation’s valuable estuarine systems while also providing for the efficient use of public funding and resources.

Phytoplankton community structure responses to urban effluent inputs following Hurricane Katrina. James L. Pinckney (presenter), Meghan Jelloe, Michael Coggins and Danielle Johnson. University of South Carolina, Columbia, SC.

As a result of failures in the levees and floodwalls protecting New Orleans, 75-80% of the city was flooded in the wake of Hurricane Katrina. To remove the floodwaters, the U.S. Army Corps of Engineers led the pumping of roughly 224 billion gallons of water from New Orleans over a 43-day period following the hurricane. The floodwaters pumped back into Lake Pontchartrain contained toxic chemicals, carcinogens, pathogens, and human waste as well as high concentrations of nitrate and phosphate. The rate of loading of these contaminants was
unprecedented and presented a unique opportunity to describe ecosystem responses to this
catastrophic event. Documentation of changes in phytoplankton community composition
provided a sensitive bioindicator for quantifying potential shifts in ecosystem structure in the
weeks following Hurricane Katrina. The overall objective of this study was to quantify the short-
and long-term responses of the phytoplankton community to massive inputs of untreated
floodwaters into Lake Pontchartrain.

Water samples were collected weekly from 15 September to 15 December 2005 at
several stations in Lake Pontchartrain by a Research Team at LSU. Filtered samples were
analyzed by high-performance liquid chromatography (HPLC) to quantify photopigment
concentrations, and relative abundances of algal groups were calculated using ChemTax. The
phytoplankton response to effluent inputs was limited to the immediate vicinity of the outfalls,
and algal concentrations returned to normal levels within 45 days after the passage of Hurricane
Katrina. Chlorophyll \( a \) concentrations peaked at 25 \( \mu g \, l^{-1} \), much below “bloom” concentrations.
Diatoms and euglenophytes were the most abundant algal groups in the effluent plume. This
event offered a unique opportunity to observe how ecological processes in Lake Pontchartrain
were altered following the catastrophic addition of millions of gallons of untreated effluent.
Overall, the impacts of effluent inputs were limited to 45 days following the storm and the
system quickly returned to “normal” conditions.

Patterns and controls of forest damage following Hurricane Katrina in DeSoto National
Forest, Mississippi. John A. Kupfer (presenter), University of South Carolina, Columbia, SC.

Hurricanes are important natural disturbances structuring terrestrial ecosystems in the
U.S. Gulf and Atlantic Coast regions, modifying landscape-level patterns of forest structure and
composition, altering disturbance regimes, and affecting short-term ecological fluxes. For
example, it has been estimated that Hurricane Katrina damaged or destroyed nearly 20 billion
board feet of timber with an estimated value of more than $5 billion on five million acres of
private, public and commercial forestlands. Forest inventories indicated that one-third of the
timber damaged was concentrated in eight counties in southern Mississippi, with nearly 90% of
all damaged forestland occurring less than 100 km from the coast. Because hurricanes are
normal, integral parts of long-term system dynamics in many coastal forested ecosystems,
management plans need to recognize their occurrence and include the potential for their
occurrence. In particular, there continues to be a need for research that helps land managers to
better understand and predict ecosystem responses to hurricanes.

The goal of this research was to develop and test an empirical model of forest damage
resulting from Hurricane Katrina for DeSoto National Forest in southern Mississippi. Many
studies have highlighted how forests regenerate following severe wind events, but fewer have
analyzed how physical and biological factors interact with one another to determine patterns of
forest damage. To do so, we categorized forest damage into four classes (none, low, moderate,
heavy) for nearly 450 plots over a 153,000 ha study area using a combination of air photo
interpretation and field sampling. We then developed predictive damage models using single tree
classification tree analysis and stochastic gradient boosting and examined the importance of
variables addressing storm meteorology, stand conditions, and site characteristics in predicting
forest damage.

Overall damage classification accuracies for a training dataset (\( n=337 \) plots) were 72\%
and 81% for the single tree and stochastic gradient boosting models, respectively. For an independent validation dataset \((n=112\) plots\), classification accuracy dropped to 57% and 56%, respectively. Proportions of agreement between observed and predicted damage were significantly greater \((p < 0.05)\) than would be expected by chance alone for all damage classes with the training data and all but the moderate class for the validation data. Stand age was the best predictor of damage for both models, with forest type, stand condition, site aspect, and distance to the nearest perennial stream also explaining much of the variation in forest damage. Measures of storm meteorology (duration and steadiness of hurricane-force winds; maximum sustained winds) were of secondary importance. The results of this study show that broad-scale damage prediction for a given event is feasible and clarify how biotic and abiotic factors interact with one another to determine hurricane damage. The study also provides a first step toward the development of models identifying the susceptibility of forest stands to future events that could be used as an aid to incorporating the effects of hurricanes into forest management activities.

**Effects of Hurricane Katrina on Southern Mississippi Coastal Forest soil and water chemistry.**

James E. Moore \(^1\) (presenter), John A. Kupfer \(^2\), Sam Pierce \(^1\) and Scott B. Franklin \(^1\). \(^1\)University of Memphis, Memphis, TN and \(^2\)University of South Carolina, Columbia, SC.

When Hurricane Katrina hit the Mississippi Gulf Shore, it brought with it a storm surge more than 9 m in height that penetrated inland up to 10 km. The main effects of storm surge on coastal ecosystems are mechanical damage from waves, salt spray damage, and chemical alterations of the soil. Thus, we asked the question, how did the storm surge from Hurricane Katrina affect soil chemistry and water quality, and what are the implications for forest stress and ecosystem resiliency? We performed repeated sampling of water and soils in storm surged and non-storm surged forests and salt marshes located around St. Louis Bay, MS. Sites were classified as hydric or non-hydric depending on soil and vegetation. Soils were collected from nearly 30 site locations in early October 2005 (one month after Hurricane Katrina), December 2005, February 2006, and December 2006. At each site, ten soil plugs, 10 cm diameter and 10 cm in depth (A horizon), were extracted randomly from the site area and mixed thoroughly. Water data, 50 sites including creeks, rivers, backwater areas, and salt-water marsh, were collected using a YSI probe in October 2005, February 2006, and December 2006; data included conductivity, salinity, pH, dissolved oxygen and temperature.

One month after the hurricane, water bodies within the storm surge zone showed statistically higher pH, conductivity, and salinity compared with those outside the surge zone. Water acidity showed no differences in surge and non-surge zones five months after Katrina. In storm surged areas, conductivity and salinity decreased from October to February, while dissolved oxygen increased. Both conductivity and salinity remained higher in December 2006 (more than one year after Hurricane Katrina), but only conductivity was significantly higher. Dissolved oxygen was significantly higher in cooler months (February and December), but was unrelated to surge. The initial pulse was expected, but the data suggest that recovery is not yet complete as chemical alterations caused by the surge are still being leached from the landscape.

Soil pH mimicked water pH, being significantly higher one month after Katrina, and returning to non-surge levels by February 2006. Soils in storm surged areas had significantly higher concentrations of sodium, phosphorous, magnesium, calcium, and potassium during all samplings following Katrina, but also show a general pattern of recovery to non-surge zone levels. Hydric soils seemed to maintain higher concentrations for a longer period of time. Effects of the surge certainly lasted into the growing season following the late summer hurricane.
Aluminum toxicity, especially in non-hydric soils, may have been a factor initially following Katrina, with levels over twice at high in surge zones. Aluminum levels in all sites decreased substantially by December 2006 and were not significantly different among sites. Organic matter initially increased in December 2005 and February 2006, but by December 2006 had declined to lower levels than September 2005, suggesting microbial decomposition during the growing season following Katrina.

With such strong differences in surge and non-surge zones and few differences occurring temporally in non-surge zones, we found no evidence of a salt-spray effect further inland from the surge zone. Forest recovery following natural disturbance is a function of effects of the disturbance on existing communities, responses of surviving individuals to changing and often stressful environmental conditions based on species-specific adaptations and life history traits, and germination and establishment of new individuals from the soil seed bank or colonization. Our data suggests forest recovery in the non-surge zone will be less affected by chemical changes to soil, and more affected by wind. Forests in the surge zone, however, were put through several stressful ecological filters. Recovery of these forests is a research aspect we plan to pursue.

Discussion & Summary

An important theme that runs through all of the papers presented in this symposium and was at the heart of the CRISIS Initiative is that of resilience. In the ecological literature, the concept of resilience has two meanings, both related to system state and disturbance (Gunderson 2000). As originally applied to ecological systems by Holling (1973), resilience refers to the persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables. The more resilient a system is, the larger a disturbance it can absorb without shifting into an alternate regime. The second definition of resilience focuses more explicitly on the responses of an ecosystem following a disturbance, for example, its ability to return to a ‘steady state’ following a perturbation (e.g., Pimm 1991). This second conceptualization of resilience emphasizes post-disturbance changes, distinguishing it from a system’s ability to ‘absorb’ disturbances, which is often referred to as ‘resistance’ or ‘inertia’ in this context. Westman (1978) and Malanson et al. (2007) provide a link between the two definitions in recognizing four components of resilience: 1) elasticity, the rate of recovery (e.g., changes in similarity to the pre-impact conditions over time), 2) malleability, the degree to which a ‘recovered’ system differs from its pre-impact state, 3) amplitude, the amount of change that can occur before a system cannot recover toward its pre-impact condition (i.e., a system threshold beyond which recovery is impossible), and 4) hysteresis, the degree to which the path of recovery varies from the path of impact-change.

The papers in this symposium address both aspects of resilience with respect to the effects of Hurricane Katrina. Previous genetic work by Quattro, Roberts and their colleagues, for example, documented significant population-level genetic subdivision in the grass shrimp *Palaemonetes pugio* along the U.S. Gulf Coast prior to Hurricane Katrina, leading them to explore questions concerning the impacts of the hurricane on genetic differentiation among coastal populations. Their post-Katrina comparisons of genetic diversity among impacted areas and between impacted/non-impacted areas, however, suggested that Hurricane Katrina had minimal impact on the population genetics of this estuarine-dependent crustacean. Kupfer examined how initial forest damage resulting from Hurricane Katrina was influenced by a range.
of biotic and abiotic factors, including stand characteristics (e.g., age, forest type, stand condition), topographic setting (e.g., site aspect, distance to the nearest perennial stream) and storm meteorology (e.g., duration and steadiness of hurricane-force winds; maximum sustained winds). His findings underscored the differences between forests that generally suffered minimal hurricane damage and whose dynamics should change little in upcoming years (particularly young, pine stands on sheltered slopes and uplands) and those stands that suffered severe canopy mortality (especially old age, bottomland hardwood stands) and whose future successional dynamics will dictate the eventual level of ‘resilience’ displayed by these stand types.

In addition to those studies focused primarily on ecological impacts due to hurricane effects, other papers addressed short-term, post-disturbance recovery. In their study of phytoplankton communities in Lake Pontchartrain, Pinkney et al. found that the impacts of effluent inputs were limited to just 45 days following the storm, with the system quickly moving toward pre-disturbance conditions. Moore et al. similarly found substantial changes in a number of soil characteristics and surface water conditions in areas affected by storm surge, but flushing of the surface soils was well underway within the first 18 months following the storm. Although forests in the surge zone were put through a stressful ecological filter and their recovery will have to be monitored in years to come, the picture that emerges from these, and other studies, is one of generally resilient environmental systems. In other coastal systems, however, researchers have shown that storm effects clearly pushed ecosystems past a threshold, resulting in extensive and likely irreversible damage (e.g., coastal marshes and barrier islands damaged by uprooting, excessive sedimentation, erosion, and mortality of dominant and keystone species; Barras 2006).

While the concept of resilience has its roots in ecology, physics and systems theory, it has increasingly been applied to the dynamics of coupled social-ecological systems (Walker et al. 2006). In hazards and disaster research, resilience refers to “the ability to survive disasters without significant loss, disruption, and stress, combined with the ability to cope with the consequences of disasters, replace and restore what has been lost, and resume social and economic activity in a timely manner” (National Research Council 2006). Resiliency of coastal zone communities has been of particular interest in the last few decades as intensified development along the nation’s coasts continues to place more property and people at risk from a range of natural hazards, including tropical storms, hurricanes, tornadoes, flooding, shoreline erosion and sea-level rise.

Most potential losses in coastal areas do not stem from unexpected events; rather, they are the semi-predictable results of interactions among the biophysical environment, the social and demographic characteristics of the communities that experience them, and the built environment (Heinz Center 2003). As it has become increasingly clear that problems associated with natural hazards cannot be solved in isolation but rather are symptoms of broader, more basic social and political issues, the practice of vulnerability analysis has shifted from an emphasis on nature as the cause of disasters toward an understanding of the role that humans play in creating vulnerability. For example, assessing the vulnerability and response capability of a specific coastal region requires an understanding of not only its population characteristics and distribution, but also the economic and political systems that largely determine how hazard vulnerability is conceptualized and distributed among and between people and places.

Resiliency of coastal communities to natural disasters such as hurricanes has been defined as a function of: 1) exposure, 2) susceptibility (vulnerability) and 3) response capacity (Cutter 2003; Turner et al. 2003). Exposure refers to the degree, duration, and/or extent to which a system is in contact with, or subject to, a given hazard, or alternatively, the probability of an
event occurring (e.g., the frequency of a land-falling hurricane at a particular location). It also includes the number of people, buildings, or infrastructure potentially at risk, all of which have increased dramatically along U.S. coastlines in recent years. The combination of increasing population and building, increasing sea level rise, and increasing storm intensity under global warming suggest exposure will increase as well.

A community’s susceptibility or vulnerability to external threats or disturbances are a function of its physical, economic, socio-cultural and ecological assets or ‘capital’ that themselves are associated with vulnerabilities related to biophysical systems, the built environment, and socio-economic systems. Biophysical factors involve the interaction between physical processes and human activity and can originate from diverse phenomena such as natural hazards (floods, earthquakes, coastal storms), technological failures (industrial accidents, chemical spills), or more routine and/or chronic environmental threats, such as pollution, coastal erosion, or global warming (Heinz Center 2002). The level of biophysical vulnerability can be dictated by a number of factors, such as proximity to the source of the threat or topography of the area, or through human actions that modify the natural landscape (e.g., residential development in coastal areas; conversion of coastal wetlands), as was also shown in Kupfer’s examination of forest landscape windthrow patterns. An important example of this is that salt marshes along the Gulf Coast and mangrove swamps throughout the world appear to serve the important service of buffering the influence of storms. Built environment indicators provide a measure of the potential economic loss of structures (houses, industries), infrastructure (highways, bridges, power facilities), lifelines (hospitals, fire stations), and cultural icons and monuments (churches, parks) that influence the overall economic vitality and livelihood of communities. Socio-economic factors are those related to the individual characteristics of people (age, gender, race/ethnicity, socioeconomic status, occupation, health status) that make them more susceptible to harm from environmental threats.

The third component of resilience is response capacity, that is, the ability of a community to ‘bounce back’ following an event. The interaction between natural and human systems is a key indicator of response and thus resilience. For example, while it is well documented that social networks and capital as well as a “sense of place” within communities may be key predictors of community resilience following events such as hurricanes, economic recovery in some communities may be tied to a greater ability of ecosystems to withstand damage or for damaged ecosystems (e.g., forests, shrimp or fishing grounds) to recover, meaning that measures of ecosystem resilience should be considered as indicators of broader community resilience. In other words, understanding aspects of resilience for the full range of components in social-ecological systems (and how they are linked) is an important pursuit for understanding the response and future behavior of the entire system (e.g., Boruff et al. 2005).

While this theme was clearly present in all of the studies in this symposium, Walker, Fletcher and their colleagues perhaps most clearly demonstrated it in their study at the Grand Bay (MS) National Estuarine Research Reserve. Their findings suggested that there was little immediate impact on salt marsh ecosystems, and they concluded that these systems, as might be expected, were highly resilient to hurricane damage. In contrast, developed areas experienced extreme and persistent damage. The researchers’ experiences at Grand Bay led them to develop a prototype for a rapid-response plan to facilitate documentation of near-term impacts in future storm events that will identify personnel and sampling locations, define the necessary logistics, establish reliable lines of communication, identify roles and responsibilities, and serve as a guide for development of other site-specific plans for additional estuarine sites. Such plans (and
specifically the data made available through carefully proscribed sampling and monitoring protocols) are necessary because of the inherent importance of these critical ecosystems to the larger communities of which they are a part.

**Conclusions**

In his introduction to the CRISIS program, Dr. Harris Pastides, Vice President for Research and Heath Sciences at the University of South Carolina, noted that:

“Coastal resiliency has obvious relevance for South Carolina. Our coastline measures 2,876 miles when all our bays, inlets, and islands are considered. There are 504,000 acres of coastal marshes. Almost a million people call our 6 coastal counties home. More than 8 billion dollars of the state's tourism revenue is generated along the coast. Knowledge derived from the natural, engineering, health and social sciences, as well as the humanities, is essential for the development of the data, models, tools and understanding that will enable critical improvements in coastal resiliency in the future. Advancements in our understanding of coastal resilience and vulnerability science also provide USC an opportunity to translate state-of-the-art research findings to public-policy decision making, while demonstrating the relevance of university-based research to improve our state, region and nation and underscoring why USC is poised to play a major role in responses to future natural and willful disasters.”

While Dr. Pastides was specifically citing the relevance and benefits of the CRISIS projects to the university and the residents of South Carolina, his comments apply to the larger U.S. coastal community. Human populations in counties bordering the Gulf and Atlantic coasts grew from 11 million to more than 53 million people from 1900-2000, with the value of insured property increasing at an even faster rate. Recent events such as Hurricane Katrina have shown that it is crucial for decision makers to have systematic metrics for assessing a community’s ability to prepare for, respond to, mitigate the effects of, and recover from environmental hazards, in other words, a clearer grasp of the resilience of coastal communities and ecosystems. The papers presented at this symposium provided a glimpse into aspects of resilience following Hurricane Katrina for various ecological communities that provide important economical and ecological services. In these few studies, the ecosystems examined were more resilient than the built environments; however, the importance of maintaining healthy, resilient ecosystems that may help to confer resilience on human coastal communities (e.g., through storm buffering or economic recovery) highlights the need to not only examine post-disturbance responses but also to monitor ecosystem conditions through time.

**References**


**References:**


